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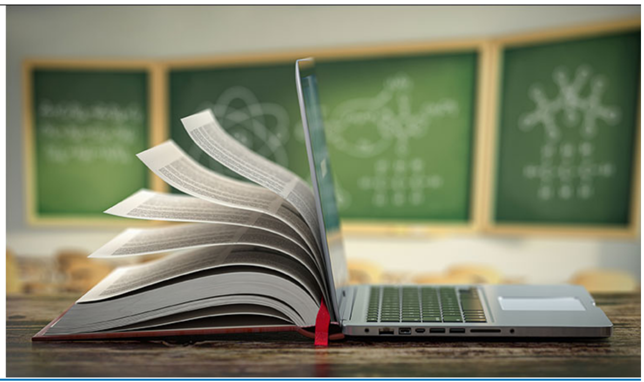

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Seismic resistance evaluation of high-rising structures under ductility level earthquake by nonlinear static method

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Abstract. Multimodal nonlinear static method for the high-rising structures' seismic resistance evaluation has been considered in this article. The object of the study is 80-meters high wind power plant. The method for account of the higher vibrations' modes and characteristic point search modified algorithm have been offered. For results verification of the systems under ductility level earthquake the nonlinear time history analysis has been performed. According to the comparative analysis the results difference between two methods does not exceed 12%.

Introduction

Generally, the high-rising structures seismic resistance evaluation under ductility level earthquake is performed using time history nonlinear analysis. Dynamic calculations are carried out taking into account inelastic deformations and local fractures in the structural elements. Time history analysis most accurately describes the system's response under the earthquake, but time consumption significantly increases. As an alternative for the inelastic deformation demands' seismic estimation, nonlinear static procedure (NSP) is considered. Seismic demands are computed by the nonlinear static analysis of the structure, which is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. The proposed inertial forces distribution does not take into account the higher vibration modes influence on the overall system response. As a decision time-varying internal forces system was proposed [2, 3, 4]. The researches [5, 6, 7] suggest additional NSP-procedure with the internal forces' distribution corresponding to higher vibration modes.

In the researches [8, 9] multimodal nonlinear static procedure (MNSP) was proposed. This method allows to take into account the required number of higher vibration modes. MNSP procedure simplifies the characteristic point search on the capacity curve due to the new criteria - system energy intensity. MNSP procedure is described in the article, and the seismic evaluation of wind power plants

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was provided by two performance-based design methods: time history analysis and multimodal nonlinear static procedure.

1. Higher vibrations modes accounting method

To determine the system response with higher vibration modes influence, the "internal forces modified system" term was used. Internal forces modified system is obtained by the forces summation of the squares method (SRSS) sum square root [10], which corresponds to the deformed system shape according to the response spectrum analysis (RSA). An inertial forces summation graphical representation is presented in Figure 1

Thus, the inertial forces modified system can be determined by the expression (1):

$$R_{sum} = \alpha \left(\sum_{i=1}^{n} R_i^2 \right)^{\frac{1}{2}} \tag{1}$$

where R_i is the modal response, corresponding to its vibration mode;

$\alpha = {}^{\Delta_{RSA}}/_{\Delta_{SRSS}}$ is the reduction coefficient, equal to the ratio of the maximum top displacement Δ_{RSA}, obtained via the response spectrum analysis to the displacement Δ_{SRSS}, obtained via modified inertial forces system.

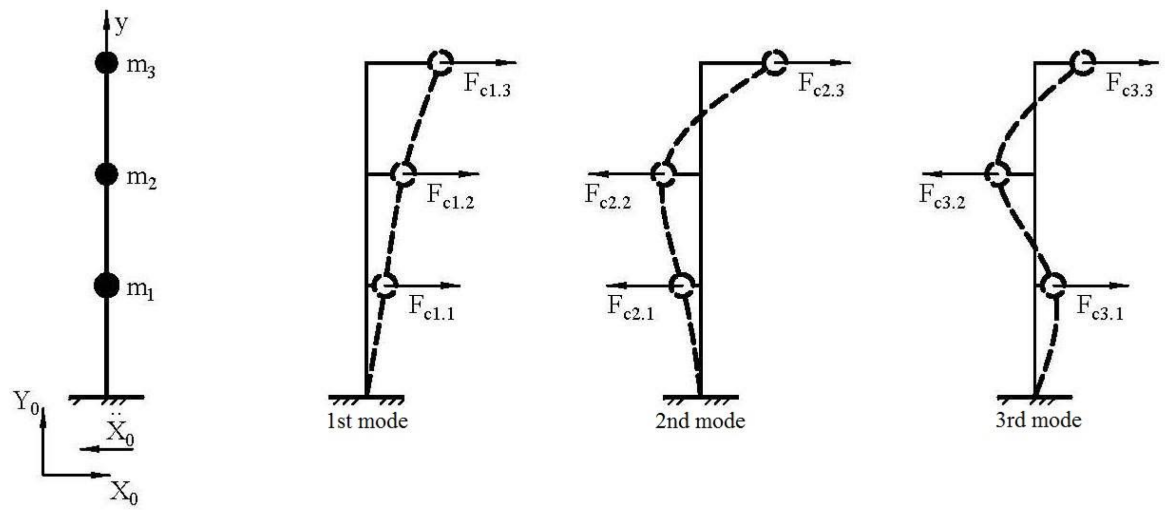

Figure 1. Graphical representation of the summation modal response method "Square Root of the Squares Sum"

According to [11], [12] to destroy the structure, no matter what the load will be applied (i.e. static or dynamic load; single or multiple), it is necessary to expend the same amount of energy (Figure 2). Thus, the linear system strain energy with an inertial forces modified system is identical to the system strain energy with plastic behaviour taken into account. The system target energy intensity can be determined as:

$$W_y = \frac{V_l \Delta_l}{2} \tag{2}$$

Where V_l is the shear force at the system base, obtained by the response spectrum analysis;

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Δ_l is the system top displacement.

The next step of the MNSP-procedure is the capacity curve plotting based on non-linear static calculation of the freedom system single degree under the inertial force modified system. The obtained top displacement is the target value for seismic resistance evaluation. According to the target displacement it is possible to determine the interstory drifts, internal forces and also analyze the plastic hinges location.

Depending on the of the characteristic point position on the capacity curve, it is possible to evaluate the structural damage.

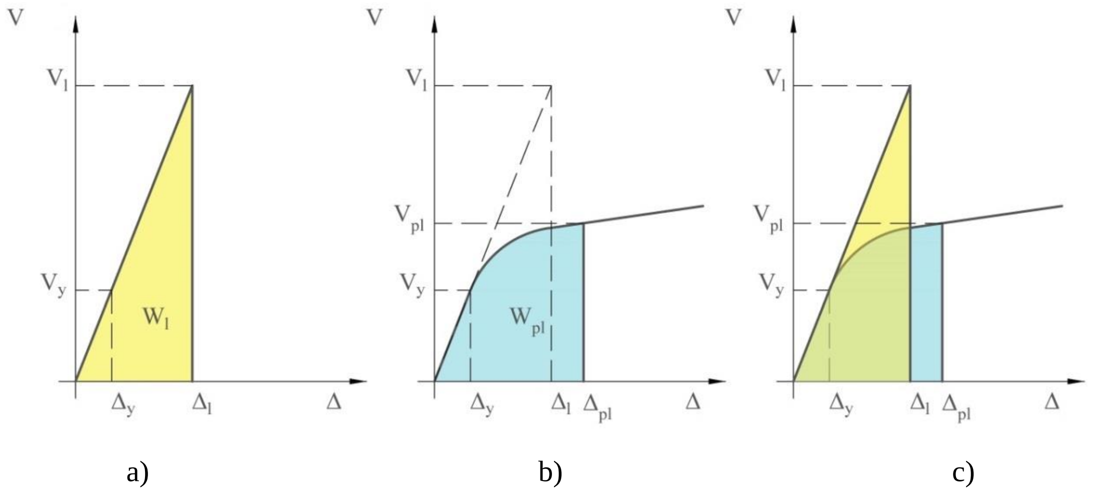

Figure 2. System energy intensity: a) elastic behavior; b) elastoplastic behaviour; c) equality of energy during elastic and elastoplastic behaviour

2. Wind power plant calculation model description

Modern wind turbines are the machines that convert wind energy to rotating wind wheel mechanical energy, and then into electrical energy. A general view of such installations is shown in Figure 3.

Figure 3. Wind power station Acciona AW-82-1500 at the Adygea wind power station

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Wind power plants consist of the following main components:

- A wind wheel (rotor) converts the incident wind energy to the mechanical rotation energy. The rotation frequency ranges from 15 to 100 rpm;
- Multiplier is an intermediate link between the wind wheel and the electric generator, which increases the wind wheel shaft rotational speed and ensures the coordination with the generator speed;
- Tower is the structural element for the wind wheel. The high-power wind plant tower height reaches 100 m;
- Foundation.

The wind turbine dynamic characteristics are presented in Table 1.

The estimated construction site seismicity was adopted according to the seismic micro-zoning results. The initial seismic impact is specified by a one-component accelerogram shown in Figure 4.

Structural steel was chosen as a material for the dynamic model. The stress-strain diagram is shown in Figure 5. To describe the nonlinear material, the isotropic hardening model (Bilinear Kinematic Hardening) was adopted [13]. The yield surface is described by the Von-Mises criteria. The stiffness and frequency characteristics are shown in Table 1. The ANSYS calculation model general view is presented in Figure 6.

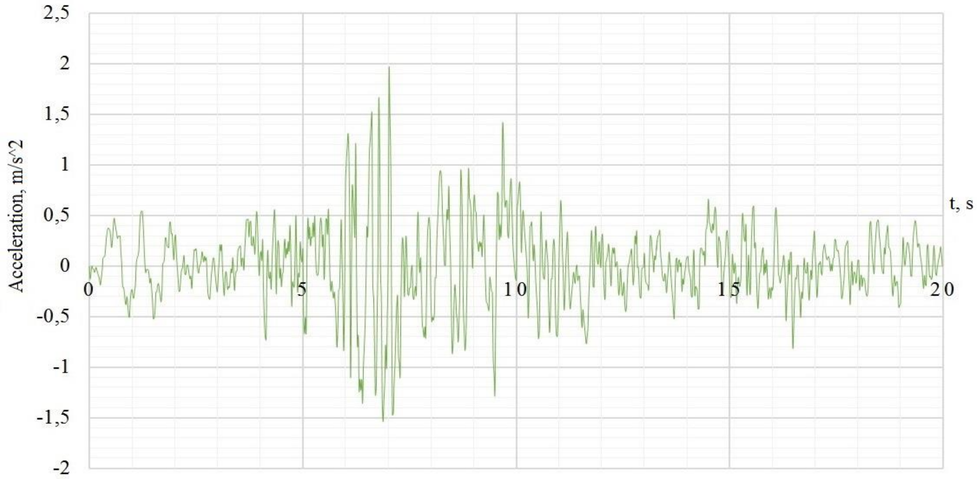

Figure 4. Horizontal component accelerogram

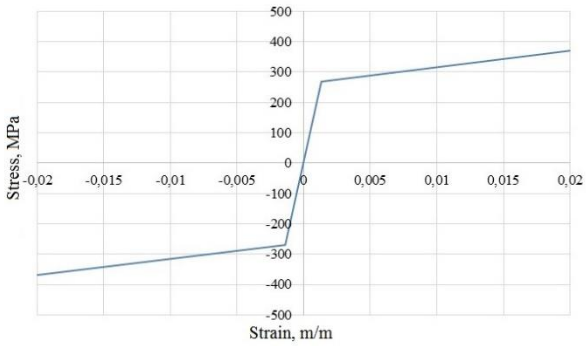

Figure 5. Stress-strain diagram

Figure 6. ANSYS calculation model

Table 1. Dynamic model characteristics

№	Nomination	Value
1	Young modulus, *MPa*	$2e^{11}$
2	Yield point, *MPa*	*270*
3	Tangential modulus, *MPa*	$5.361e^{3}$
4	1^{st} natural vibration frequency f_1, *Hz*	*0.3752*
5	2^{nd} natural vibration frequency f_1, *Hz*	*0.93285*
6	3^{rd} natural vibration frequency f_1, *Hz*	*2.6817*
7	Tower height, *m*	*80*
8	Rotor mass, kg	*102200*

3. Results

To estimate the structural elements seismic resistance by MNSP-procedure the inertial forces modified system was calculated according to the expression (1). The calculation results, reduction coefficient, base shear force, energy intensity are shown in Table 2.

Table 3 shows the results difference between two performed based design methods.

Table 2. The calculation results obtained by MNSP-procedure

№	Nomination	Value
1	Inertial force at the upper node, *kg*	*12951.41*
2	Inertial force at the middle node, *kg*	*10218.39*
3	Inertial force at the lower node, *kg*	*9419.69*
4	Sum of the modal masses, *%*	*98.689*
5	Upper node maximum horizontal displacement obtained by RSA, *mm*	*129.07*
6	Upper node maximum horizontal displacement obtained under the inertial forces modified system, *mm*	*217.44*
7	Reduction coefficient α	*0.59359*
8	Maximum base shear force obtained under the inertial forces modified system, *kN*	*189.71*
9	Potential strain energy / Energy intensity, *kJ*	*122.42*
10	Upper node maximum horizontal displacement obtained by MNSP-procedure, *mm*	*130.71*
11	Middle node maximum horizontal displacement obtained by MNSP-procedure, *mm*	*59.58*
12	Lower node maximum horizontal displacement obtained by MNSP-procedure, *mm*	*16.05*

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Table 3. The calculation results errors

Parameter		Time history nonlinear analysis	MNSP-Procedure	Error, %
Horizontal displacement, *mm*	*Upper node H=80 m*	*133.99*	*130.71*	*-2.45*
	Middle node H=52 m	*56.23*	*59.58*	*+5.62*
	Lower node H=26 m	*14.27*	*16.05*	*+11.09*

Summary
In the mathematical research the process static and dynamic calculations were performed using the ground acceleration records, the capacity curve for the wind power plant structural elements was plotted. As a result of seismic resistance evaluation the characteristic point was found.

To account higher vibration modes MNSP-Procedure was used. The results were compared to the results obtained by the nonlinear time history analysis. The maximum error does not exceed 12 % and provide the structural seismic resistance. The automation algorithm was proposed by the authors [14].

It is noted that at a lower cost of calculation time the multimodal nonlinear static procedure can be a good alternative for nonlinear time history analysis.

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